



DEPARTMENT OF GEOGRAPHY
UNIVERSITY OF SOUTH CAROLINA
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**INTEGRATING CLIMATE SCIENCE AND WATER MANAGEMENT
IN NORTH AND SOUTH CAROLINA**

FINAL REPORT

Award # NA06OAR4310007
Submitted September 25, 2012

1. TEAM MEMBERS

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2. OVERVIEW

The purpose of this project was to develop and conduct an applied research program that integrates social and natural sciences in order to characterize the risks, vulnerabilities, and potential impacts of climate variability and change across the Carolinas. Activities involved advancing scientific understanding of climate and hydrological processes in the Carolinas, improving the assessment of climate-related vulnerabilities and impacts, and providing timely and relevant information and tools for decision-makers. Regional engagement helped us build a network among decision makers in the water resources and coastal management sectors and collaborative partnerships with other federal, regional, and state climate service providers. By emphasizing processes that facilitate learning, we helped to foster information exchange among decision makers, researchers, and climate service providers. During this award period, core activities encompassed three general focus areas: drought, climate and watershed modeling, and coastal climate. From 2010 to 2012 the team also conducted studies to support the U.S. National

Climate Assessment. Specific projects and accomplishments are described in the following sections.

3. PROJECT HIGHLIGHTS

- Developed the **Dynamic Drought Index Tool (DDIT)**, a web-based drought monitoring and mapping tool that allows users to calculate and display drought indices at the spatial and temporal scales most relevant to their decision making.
- Developed and completed several projects **to advance regional and local capacity to cope with drought**, including workshops to understand regional needs for a drought early warning system, a state of knowledge report about drought impacts on coastal ecosystems, and domestic water quality monitoring with the Georgia Tribe of the Eastern Cherokee and the Lower Muskogee Creek Tribe.
- Calibrated EPA's BASINS Hydrologic Simulation Program-Fortran (HSPF) models for the Yadkin Pee-Dee (from the NC mountains to the coast), Waccamaw, and Black Rivers at the 8-digit HUC level in order **to address local hydroclimatological variability within each watershed**.
- Linked hydrologic models with a salt-water intrusion model **to assess salinity threats to surface water resources in coastal areas**. A web-based decision-support tool allows users to evaluate scenarios and adaptation options.
- Used dynamical and statistical downscaling **to assess the regional impacts of climate variability and change in the southeast**. This research was also used to improve understanding of climate change effects on riparian systems at Congaree National Park.
- Partnered with North Carolina Sea Grant and South Carolina Sea Grant Consortium to develop the “**Carolinas Coastal Climate Outreach Initiative**.” This initiative supported a regional climate extension specialist to deliver hands-on technical support and outreach programs for coastal communities, resource managers, and interest groups.
- Developed the **Vulnerability and Consequence Adaptation Planning Scenarios (VCAPS)**, a process that integrates local and scientific information and helps decision-makers in small municipalities explore the potential consequences of climate change in their towns, along with pathways through which they may respond.
- Conducted research about adaptive capacity and adaptation in the region and submitted three reports as technical inputs to the **National Climate Assessment**.
- Offered **over 100 presentations and workshops** to a wide range of stakeholders and decision makers, including education and outreach communities, government agencies, and researchers.
- **Expanded CISA's research capacity** by adding a full-time program-research manager and post-doctoral researcher to the core office staff.
- Established an **Advisory Committee** to provide guidance to the CISA PIs and staff about developing regional collaborations, identifying and addressing key decision maker needs in the Carolinas, and implementing new projects. Members include Jeff Allen (Clemson University, SC Water Resources Center), Margaret Davidson (NOAA Coastal Services Center), Braxton Davis (NC Division of Coastal Management), Rick DeVoe (SC Sea Grant Consortium), Jerry McMahon (DOI Southeast Climate Science Center), Tim Owen (NCDC), Linda Rimer (EPA Region 4), David Stoney (Kitchen Table Climate Study Group, McClellanville, SC), Lauren Thie (NC Division of Public Health), and Mike Voiland (NC Sea

Grant, Water Resources Research Institute), and Ellen Mecray (NOAA Regional Climate Services Director-Eastern Region, ex officio).

4. PROJECT DESCRIPTIONS AND ACCOMPLISHMENTS

4.1 DROUGHT

CISA's drought work focused on improving monitoring methods, developing a more comprehensive understanding of regional impacts, and assessing drought planning and early warning needs.

4.1.1 Implementation of a Drought Mapping Tool in the Eastern United States (Carbone, Rhee, Mizzell, Dow)

Partners: Northeast Regional Climate Center (A. DeGaetano, B. Noon, K. Eggleston), Southeast Regional Climate Center

Abstract: The Carolinas Dynamic Drought Index Tool (DDIT) was developed to support water-resources planners and managers in the Carolinas. The prototype allows the flexible depiction – using maps, graphs, and tables – of drought conditions for user-specified time scales and regions. CISA obtained funding through NOAA's Transition of Research Applications to Climate Services (TRACS) program to expand DDIT coverage from the Carolinas to eighteen states across the eastern U.S. served by the Northeast and Southeast Regional Climate Centers (NERCC & SERCC, respectively).

Results: The DDIT prototype consists of three parts: a numerical model that calculates percentiles for each drought index and performs spatial interpolation and averaging; a database that stores the results from the numerical model; and a graphical user interface – developed using Scalable Vector Graphics (SVG) with server-side scripting language PHP (PHP: Hypertext Preprocessor) and JavaScript – that provides users options for selecting drought indices, blending percentages, and classification methods as well as resultant maps, graphs, and tables. We worked with the NERCC to facilitate the transition of the tool to operations. This work comprised five parts: (1) building appropriate spatial databases; (2) optimizing current spatial data handling techniques; (3) linking the drought tool to the Applied Climate Information System (ACIS) to enable near real-time display; (4) incorporating user suggestions to improve functionality of the tool; and (5) working with user groups to evaluate its effectiveness in decision making. This work has resulted in the redesign of the DDIT to accommodate gridded (vs. station) data and to transfer from SVG to web services calls. Additional, related projects have been conducted and are described below.

Testing the sensitivity of drought indices to missing data

A study was conducted to address the shortcoming issues for drought index estimation and investigated various methods for filling missing daily precipitation data, handling short-term records, and obtaining drought information for unsampled locations. The findings of this study revealed that the best strategy is to spatially interpolate missing daily precipitation from nearby stations and then calculate SPI values. These sensitivity tests of the drought indices to missing

data demonstrate the possibility of the use of precipitation data from other sources for drought monitoring for areas without any in-situ measurements.

Cognitive cartographic research

We explored effective ways to measure and communicate the uncertainty inherent in drought maps by testing the effectiveness of visualization strategies to display drought indices concurrently with uncertainty measures. This cognitive cartographic study measured user interpretation of uncertainty symbols in drought maps. The most intuitive symbols for expressing uncertainty were Saturation, Opacity, Fill clarity 1 and 2, Extrinsic2, and Texture 3. Subjects perceived Extrinsic 2, Fill clarity 1, Opacity, Area filled, and Saturation as most effective at communicating drought data's uncertainty (Figure 1). We also learned that subjects are less likely to interpret the symbols accurately when the drought level at a station is not the same as the drought level for the area of interest.

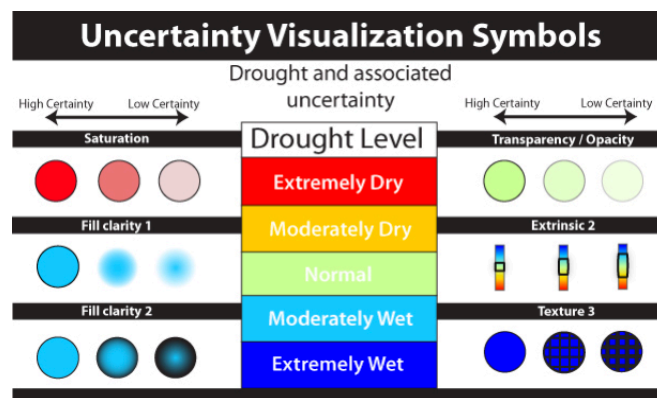


Figure 1. Uncertainty Visualization Symbols Tested for Drought Mapping Applications

Examining the robustness of drought triggers used in decision making

Indicators are used to measure drought intensity, and management plans use drought triggers in planning response. Accurate and reliable indicators are necessary for effective decision making before, after, and during drought. Decision makers typically rely on multiple triggers without realizing their spatial and temporal inconsistencies. Mizzell compared seven drought indicators defined in South Carolina's Drought Response Program regulations. The study identified inconsistencies in the frequency of drought stages according to different indicators. For example, the bar chart below (Figure 2) shows that several indicators would place South Carolina in a drought between 40-50% of the time. Figure 2 also shows that the Crop Moisture Index (CMI) and streamflow vary most from other indicators at the severe and extreme levels. Streamflow has the lowest occurrence (5.84%) of all drought levels combined. Although there are consistencies between the Keetch Byram Drought Index (KBDI) and groundwater indices, these are not based on similarities in calculation.

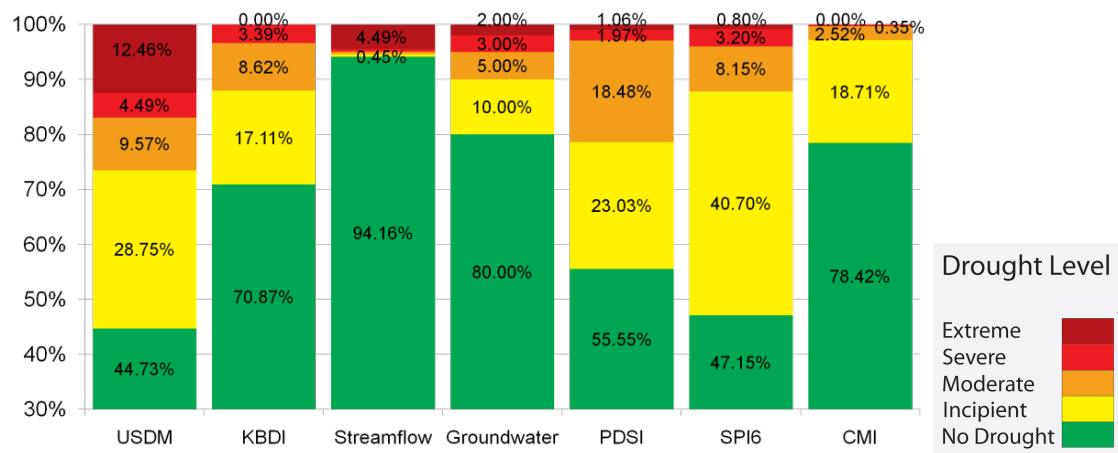


Figure 2. Comparison of the Frequency of Drought Indicator Level

When comparing the seven South Carolina drought indicators for one station in Florence during the period, January 2000—April 2009, the difficulties in determining when a drought begins, when it changes levels, and when it ends become obvious. For example, in 2005-2006 streamflow indices are frequently in severe and extreme stages while other indices are at incipient or normal levels. This inconsistency has important implications for determining action in response to drought levels.

The differences among many of the indicators can primarily be attributed to the inconsistencies in the drought level ranges defined by South Carolina’s drought regulations. In the DDIT, our solution for using multiple and often statistically inconsistent indicators is to transform all indicators to percentiles (Steinemann and Cavalcanti 2006)¹. The DDIT can be used to calculate percentile indicators.

Leveraged Funding Source

- “Implementation of a drought mapping tool in the eastern United States”. Carbone, G.J., A. DeGaetano, K. Dow, H. Mizzell, J. Rhee. NOAA TRACS. September 2007. 1 May 2008 – 30 April 2012. \$249,570.

4.1.2 Advancing Regional and Local Capacity to Cope with Drought (Dow, Tufford, Lackstrom)

Partners: National Integrated Drought Information System (NIDIS), National Drought Mitigation Center (NDMC), NC and SC State Climate Offices, Southeast Indigenous Peoples’ Center (SIPC), Southeast Regional Climate Center (SERCC)

Abstract: “Coping with Drought” projects included engagement with a range of stakeholders to determine their decision-support needs, develop ways to transfer tools and information to decision makers, and identify opportunities and regional activities through which NIDIS can support those needs.

¹ Steinemann, A.C. and L.F.N. Cavalcanti. 2006. Developing Multiple Indicators and Triggers for Drought Plans. *Journal of Water Resources Planning and Management* 132 (3): 164-174.

Results: Research centered on understanding drought impacts on social and environmental systems currently under-represented in regional drought assessments, including coastal ecosystems and indigenous people, and the decision-support needs of those groups. Projects were conducted in collaboration with NIDIS to support their efforts to develop a drought early warning system pilot in the Carolinas.

Leveraged Funding Source: We received a supplement to our core funding from NIDIS/Coping with Drought.

Domestic water quality monitoring project

Concerns about drought impacts on groundwater quantity and quality for rural populations led to this study to understand whether vulnerability to water quality problems is elevated during drought and determine whether water level or water quality provide early indicators of drought onset or severity. Contact was made with Walker Dan Davis, Chief of the Georgia Tribe of the Eastern Cherokee in Dahlenega, GA, and Vonnie McCormick, Principle Chief of the Lower Muskogee Creek Tribe outside Whigham, GA. Tufford visited with these tribal representatives in fall 2011-winter 2012 to discuss the project and assess their property for suitable study sites. Tufford and a field technician installed small shallow monitoring wells at the two locations in April 2012. The Chiefs and spouses were trained how to use the monitor device and have been taking measurements once every two weeks. Water samples from the wells continue to be collected and brought to USC for laboratory analysis.

Research to understand regional needs for a drought early warning system

CISA conducted workshops in March 2010 to learn about drought concerns, stakeholders' use of drought data and preferences for new tools and information, and users' requirements for a drought early warning system. The workshops were conducted with water system managers from the North Carolina Urban Water Consortium and stakeholders engaged with South Carolina coastal ecosystems. Results were documented in two technical reports.

The Impact of Drought on Coastal Ecosystems in the Carolinas - State of Knowledge Report

This effort was based on participant recommendations from the workshop mentioned above. The report provides a synthesis and analysis of the peer-reviewed literature regarding drought impacts on coastal ecosystems in the Carolinas. It expands current, limited understanding of drought impacts on coastal ecosystems, to identify critical gaps, to inform future research efforts, and to suggest measures to facilitate drought adaptation. The report generated interest at local and national levels and is being utilized to guide potential ideas for a NIDIS Carolinas pilot project.

The research reviewed for this report indicates that drought is discussed primarily in terms of the hydrology-related impacts that affect coastal ecosystems, such as changes to river discharge, freshwater inflows, water level, and water table depth. The severity of these effects depends upon the longevity and recurrence interval of drought event(s) and may be compounded by other anthropogenic stressors on the system. In addition, some drought-related research considers how sea level interacts with freshwater precipitation and runoff to influence the salinity levels experiences by these systems. The review identified the most critical needs for future research

including: examining drought impacts in ecosystems not studied by existing research, implementing long term studies to identify and examine causal relationships, and developing a set of indicators with which to monitor ecological change and impacts. More research and information is needed regarding drought impacts on groundwater resources, the significance of drought during different seasons, the longevity of droughts in relation to long-term impacts and/or length of recovery, and responses to potential future changes in salinity regimes.

Additional work to prepare for a NIDIS-Carolinas pilot project

An informational meeting was held at the “NOAA in the Carolinas” meeting on March 15, 2012. Approximately 25 people from various federal and state agencies attended. Subsequent steps entailed establishing a Carolinas NIDIS Pilot Project Steering Committee and preparing for an initial meeting (May 1, 2012 in Charleston, SC). Represented organizations include the DOI Southeast Climate Science Center, EPA Region 4, Hollings Marine Laboratory, National Drought Mitigation Center, NERRS (North Inlet-Winyah Bay), NOAA’s Center for Coastal Environmental Health and Biomolecular Research, NOAA’s Center for Excellence for Oceans and Human Health, NOAA’s Coastal Services Center, NOAA Fisheries, NOAA Regional Climate Services, The Nature Conservancy, USFWS Coastal Programs, and USGS (SC Water Science Center).

4.2 CLIMATE AND WATERSHED MODELING

CISA’s hydrological modeling projects addressed a regional need for a comprehensive analysis of watersheds to understand how climate variability and change affects water supply and quality from the mountains to the coast. Our focus on climate as a driving force and our use of models that cover large watersheds at sub-watershed scales provided meaningful information for local and regional decision making. The projects and modeling work described below are interrelated and have evolved as we have received feedback from decision-makers about their interests in understanding the plausible range of climate change scenarios for the region.

4.2.1 Modeling of the Winyah Bay Watersheds (Tufford, Carbone)

Abstract: We used EPA’s BASINS Hydrologic Simulation Program-Fortran (HSPF) model to address hydroclimatological variability in the Winyah Bay watershed. We calibrated HSPF simulation models for the Yadkin Pee-Dee (from the NC mountains to the SC coast), Waccamaw, and Black Rivers at the 8-digit HUC level so that local variability within each watershed can be adequately addressed.

Results: Water flow calibration and verification was completed for all watersheds in the Winyah Bay Watershed (Figure 3). Water quality calibration began for all of the watersheds and was completed for two watersheds. Water quality constituents included water temperature, biological oxygen demand, dissolved oxygen, and total ammonia-nitrogen, depending on the availability of observed data for each watershed. Four watersheds in the upper regions of the watershed were unable to be calibrated for water quality because of a lack of water quality data in this region.

The alternative stream geometry creation method in HSPF was adapted for use in the Coastal Plain. We manually created stream geometry using increasing channel roughness values. Sensitivity runs were conducted for two watersheds to test whether the best values had been used for calibrating water quantity. Results indicated that the best parameter values were currently being used for these two watersheds. The sensitivity of water quality parameters was evaluated using HSPF-PARM to aid in calibration. This provided a starting point for water quality calibration with the ranges of parameter values used by other researchers displayed and the sensitivity of each parameter in the model based on sensitivity runs. Additional activities included exploring how to disaggregate from daily to hourly precipitation time series for input to the HSPF model and setting up HSPF to simulate reservoir operations.

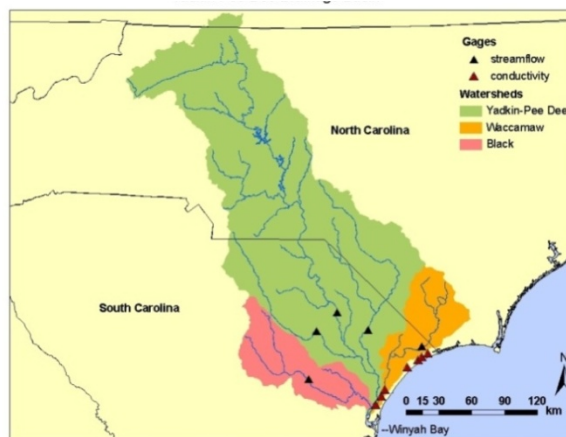


Figure 3. Winyah Bay Watershed

This basin-wide approach to hydrological modeling water managers, natural resource managers (e.g. Nc Riverkeepers, citizen-advocates, Native American agency staff. Watershed modeling activities reflect the watershed models and initial results with decision Waccamaw Watershed Academy, Waccamaw River Management in order to elicit feedback, aid ongoing watershed concerns into scenario development. Participants suggested that the models could be used to improve understanding of dissolved oxygen (DO) dynamics in the Waccamaw River – which is DO stressed, common in coastal rivers – especially under scenarios of changing precipitation patterns.

4.2.2 Assessing the Impact of Salt-Water Intrusion in the Carolinas under Future Climatic and Sea-Level Conditions (Whitehead, Tufford, Dow, Carbone)

Partners: USGS SC Water Science Center (P. Conrads), Advanced Data Mining (E. Roehls)

Abstract: The goal of this research was to develop a decision support tool that will help community water and sewer districts and coastal resources managers adapt to future changes in the fresh water supplies they have come to expect. To this end, we studied the threat of salt-water intrusion in the Yadkin-Pee Dee River basin under different climatic scenarios, with an emphasis on changes in the frequency and duration of salt-water intrusion events with increasing sea levels. The resulting tool - the excel-based Pee Dee River and Atlantic Intracoastal Waterway Salinity Model 2 (PRISM2) decision support system (DSS) - is based on an integration of climate downscaling, hydrologic modeling and Artificial Neural Network analysis of tides coupled with sea level rise estimates.

Results: The primary components of the projects were (1) empirical and mechanistic modeling of hydrologic conditions in the Yadkin-Pee Dee River system to determine freshwater discharge and resulting salinity intrusion at the coast under future climatic conditions and sea level rise, and (2) updating existing decision support tools to address salt water intrusion challenges for industry, water and sewer districts, and resource managers in the lower Yadkin-Pee Dee River basin. The project team used the EPA BASINS HSPF model (see Section 4.2.1) and the “Pee Dee River and Atlantic Intracoastal Waterway Salinity Model” (PRISM) (Conrads and Roehl 2007)² to conduct an empirical and modeling analysis of hydrologic conditions in the Yadkin-Pee Dee River system and determine freshwater discharge and resulting salinity intrusion at the coast under future climatic conditions and sea level rise. The updated PRISM2 DSS allows users to adjust sea level rise and flow levels in the Yadkin-Pee Dee Basin to generate scenarios of how future climate change (e.g. more frequent drought conditions) and sea level rise may impact the inland penetration and duration of salt-water intrusion events.

Of significance to regional stakeholders, this tool demonstrated the effects of salinity intrusion events on the frequency and duration of higher conductance values in water sources. It is problematic for the operations of municipal water treatment plants when the specific conductance values for source water are greater than 1,000 to 2,000 $\mu\text{S}/\text{cm}$. Analysis of the frequency distribution of the specific conductance response at the Pawleys Island stream gage to a 1.0 ft (30.5 cm) and a 2.0 ft (61 cm) sea-level rise for the period July 1995 to August 2009 indicated that a 1-ft sea-level rise doubled the frequency of occurrence of specific conductance above 2,000 $\mu\text{S}/\text{cm}$ to 8 percent of the days (Figure 4). A 2-ft sea-level rise quadrupled the frequency to 14 percent of the time. For the 14-year simulation period, the number of days of specific conductance level at or above 2,000 $\mu\text{S}/\text{cm}$ was 191 days for the measured sea-level conditions. A 1-ft sea-level rise increases the number of days to 399 and a 2-ft rise increases it to 697 days.

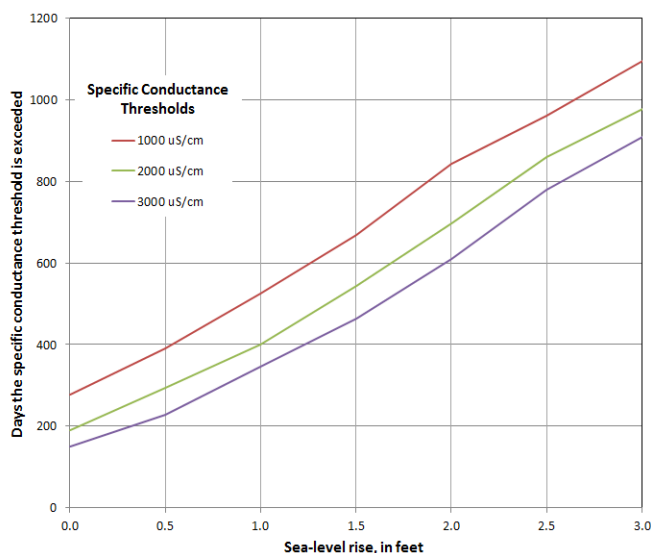


Figure 4. Plot showing the number of days specific conductance thresholds are exceeded for incremental sea-level rise on the Waccamaw River near the Pawleys Island water intake for the period July 1995 to August 2009.

² Conrads, P.A. and Roehl, E.A., Jr. 2007. Analysis of salinity intrusion in the Waccamaw River and Atlantic Intracoastal Waterway near Myrtle Beach, South Carolina, 1995-2002. U.S. Geological Survey Scientific Investigations Report 2007-2110, 41 p.

Such information can help decision makers plan for future severe events (e.g., positioning fresh-water intakes and treatment facilities, preparing for increased treatment costs) and increase the region's resilience in preparing for potential changes in the frequency and magnitude of salt water intrusion.

A follow-up workshop was held on December 14, 2011, in Georgetown, SC, in order to engage and obtain input from regional decision makers. Attendees included resource managers, water/sewer utility managers, and education and outreach specialists. Participants were introduced to three climate change scenarios and potential impacts on the frequency and longevity of saltwater intrusion events in relation to decreased streamflow, rising sea levels, and a combination of the two. Breakout sessions allowed attendees to discuss the models and provide feedback on how to improve them.

Leveraged Funding Source

- “Assessing the impact of salt-water intrusion in the Carolinas under future climatic and sea-level conditions.” J. Whitehead, PI (originally G. Zielinsky, PI); D. Tufford, Dept. of Biology, Univ. of South Carolina, Co-PI; K. Dow and G. Carbone, Dept. of Geography, Univ. of South Carolina, Co-PIs. NOAA SARP #NA08OAR4310715. Duration of Study: May 2008 – extended to June 2011. Funds awarded: \$235,717.

4.2.3 Integrating Regional Downscaling and Hydrological Models (Carbone, Tufford, Samadi)

Partner: USGS South Carolina Water Science Center (P. Conrads)

Abstract: In order to address stakeholder interest in the development of climate scenarios for water planning, CISA used dynamical and statistical downscaling to assess the regional impacts of climate variability and change in the southeast. We explored the effects that climate-related changes may have on water quality, particularly on dissolved oxygen. Our downscaling efforts centered around two data sets: regional climate model (RCM) output from the North American Regional Climate Change Assessment Program (NARCCAP) and statistically downscaled data from the Department of Interior/United States Geological Survey (DOI/USGS).

Results: This project entailed working with climate change scenarios produced for the USGS (Geo Data Portal). These data are derived from nearly 20 general circulation models (GCMs) as part of the Intergovernmental Panel on Climate Change (IPCC). Values of maximum and minimum temperature and precipitation were downscaled to a 12 km grid, commensurate with a widely-used observed gridded data set (Maurer et al. 2007)³. Downscaled data from four GCMs, including CCSM3, ECHO-2, GFDL2.0, and PCM, were processed.

Analysis focused on assessing RCM performance in the Southeast during the historical period with explanations of model bias, as well as quantification of uncertainty in future scenarios that results from differing models and downscaling methods. We examined monthly temperature and

³ Maurer, E.P., L. Brekke, T. Pruitt, and P.B. Duffy. 2007. Fine-resolution climate projections enhance regional climate change impact studies, *Eos Trans. AGU*, 88(47), 504.

precipitation changes using a verification data set of 12km gridded observed dataset from 1970 to 1999 from the University of Washington (Maurer et al. 2002)⁴ and 50km RCM historical (1970-1999) and future (2041-2070) output from NARCCAP (Mearns et al. 2009)⁵. We created probability density functions (PDFs) for the observed dataset and each RCM in a historical period using extracted data and used the PDFs to determine monthly model skill. This was accomplished by calculating cumulative minimum value of two distributions of a binned value, measuring the common area between two PDFs (Perkins et al. 2007)⁶. Skill was based on a scale from zero (low skill) to one (high skill) and used to calculate weighted average for future precipitation and temperature change. RCMs showed some skill in modeling historical temperature, especially during the warm months, but showed little skill in modeling cold season historical temperature. Precipitation skill scores were low for all months.

We also worked with a statistical downscaling data set from the DOI/USGS. These data for the Southeast represented the historical period, 1980-2009 and included daily precipitation, daily maximum and minimum temperature. We processed data as it became available and conformed it to serve as input for our hydrological modeling work. The gridded downscaling was aggregated to sub-basins within and beyond the Santee Basin. Aggregation at this scale matched that required for hydrological modeling with HSPF. Data preparation also required disaggregating daily precipitation to hourly time steps. We conducted extensive testing to evaluate HSPF performance with various disaggregation methods. We also evaluated NARCCAP data in the Southeast. We evaluated summer and winter maximum and minimum temperature, and precipitation for nine pairs of general circulation models and regional climate models.

Climate Impacts on Congaree National Park

CISA's downscaling work was also a key component of a related project to understand climate impacts on riparian systems at Congaree National Park. Project objectives included: constructing regional precipitation and temperature scenarios from downscaled general circulation models, developing profiles of river hydrology under varying climate change scenarios, translating profiles of river hydrology into corresponding maps of site hydroperiod, and producing maps of potential habitat for key indicator species at Congaree under both current conditions and projected scenarios of environmental change. Downscaling results served as inputs into multiple model simulations to analyze the effects of altered river hydrology, floodplain inundation, and resultant species distribution across the Congaree landscape.

Leveraged Funding Sources

- "Climate change-induced changes in flow regime, floodplain inundation and species habitats." Kupfer, J.A., G. Carbone, D. Tufford and K. Meitzen. US Department of the Interior, National Park Service, Climate Change Program, Congaree National Park. 2010-2013: \$310,000 awarded. (2011 funding: \$140,000).

⁴ Maurer, E. P., A. W. Wood, J. C. Adam, D. P. Lettenmaier, and B. Nijssen. 2002. A long-term hydrologically based dataset of land surface fluxes and states for the conterminous United States. *Journal of Climate* 15:3237-3251.

⁵ Mearns, L. O., W. Gutowski, R. Jones, R. Leung, S. McGinnis, A. Nunes, and Y. Qian. 2009. A regional climate change assessment program for North America, *Eos Trans. AGU*, 90(36): 311- 312.

⁶ Perkins, S. E., A. J. Pitman, N. J. Holbrook, and J. McAneney. 2007. Evaluation of the AR4 climate models' simulated daily maximum temperature, minimum temperature, and precipitation over Australia using probability density functions. *Journal of Climate* 20:4356-4376.

- “Coastal Climate Extension Specialist Support.” Carbone, G.J. SC Sea Grant Consortium/NOAA, \$18,429, 1 July 2011–30 June 2012.

4.3 COASTAL CLIMATE

CISA partnered with North and South Carolina Sea Grant to assist coastal communities and stakeholders in addressing potential impacts of climate variability and change on major coastal issues including: erosion, invasive species, land use change, salt water intrusion, health of fisheries, agriculture, tourism, coastal community development, and natural hazards. Project stakeholders included existing, traditional Sea Grant Extension audiences, e.g. marine fisheries, aquaculture, and coastal zone management, as well as relatively newer audiences among local governments, state agencies, developers, the interested public, and local non-governmental organizations.

Partners: Beaufort County Planning Department, SC; City of Charleston, SC; College of Charleston; Environmental Protection Agency (EPA); Federal Emergency Management Agency (FEMA); Florida Sea Grant; Georgia Sea Grant; Governor’s South Atlantic Alliance; Kitchen Table Climate Study Group of McClellanville, SC; Maine Sea Grant; Massachusetts Sea Grant; Mississippi-Alabama Sea Grant; National Sea Grant Office; National Weather Service (Charleston, SC; Newport, NC); NC Department of Environment and Natural Resources (DENR); NC Interagency Leadership Task Force Climate Working Group; NC National Estuarine Research Reserves; NC Sea Grant; NOAA Coastal Services Center; NOAA/NCDC Eastern Region Climate Services Director; NOAA/NCDC Southern Region Climate Services Director; NOAA Southeast Caribbean Regional Team (SECART); North Inlet-Winyah Bay National Estuarine Research Reserve; Oregon Sea Grant; Renaissance Computing Institute at East Carolina University; SC Department of Health and Environmental Control (DHEC); SC Department of Natural Resources (DNR); SC Sea Grant Consortium; Social and Environmental Research Institute (SERI); Town of McClellanville, SC; Town of Plymouth, NC; Town of Sullivan’s Island, SC

4.3.1 *The Carolinas Coastal Climate Outreach Initiative (CCCOI)* (Whitehead, Carbone, Dow, Tufford)

Abstract: In 2006 the South Carolina Sea Grant Consortium, North Carolina Sea Grant, and CISA partnered to create a coastal climate extension program. This program integrated the climate and vulnerability expertise of CISA researchers with the outreach experience of both Sea Grant programs to provide timely, relevant, and credible information on climate issues to decision-makers along the North and South Carolina coasts. The program had four objectives:

- Develop the capacity of NC/SC Sea Grant to inform and educate coastal decision-makers of the implications of climate variability and change for major coastal issues.
- Provide tailored, decision-relevant information on (a) the implications of climate variability and change and (b) adaptation strategies that increase resilience.
- Increase the regional and national capacity of the Sea Grant network to deliver outreach programs on the impacts of climate variability, climate change, and adaptation strategies.
- Evaluate and review enhancements in Sea Grant capacity and approaches in climate extension.

Results: The CCCOI supported a wide range of coastal-related projects across the Carolinas and served as a model for similar climate extension programs across the country. Jess Whitehead, who started as the regional climate extension specialist in 2008, initiated many local projects and served as a resource for state level projects as well. For example, she worked on a South Carolina DHEC project to develop guidance for South Carolina on near-term coastal adaptation priorities and was consulted by the North Carolina Interagency Leadership Team’s Climate Adaptation Working Group as they assembled a report on climate adaptation priorities for that state. Many of these projects have been supported by additional awarded leveraged funds and are described in further detail in the following sections.

Leveraged Funding Sources

- “The Carolinas Coastal Climate Outreach Initiative.” M. R. Devoe, R. Bacon, G.J. Carbone, J. Thigpen, D. Tufford, K. Dow, and J. Whitehead. Project duration: 2006-2010. NOAA National Sea Grant Office and Climate Program Office. Funds Awarded: \$300,000)
- “Carolinas Coastal Climate Outreach Initiative – Phase II – 2010-12.” M.R. DeVoe, SC Sea Grant and M. Voiland, NC Sea Grant, PIs; R. Bacon, SC Sea Grant Extension, and G. Carbone, Univ. of South Carolina, co-PIs; J.C. Whitehead, SC Sea Grant Consortium/NC Sea Grant, J.F. Thigpen III, NC Sea Grant, K. Dow, Univ. of South Carolina, and D. Tufford, Univ. of South Carolina, additional investigators. Project duration: July 2010 – June 2012. Funds awarded \$192,702 (matching funds: \$48,176).
- Guidance for South Carolina on near-term coastal adaptation priorities. B. Davis, S.C. Department of Health and Environmental Control – Office of Ocean and Coastal Resource Management, PI; S. Cutter, Department of Geography, University of South Carolina, co-I; J. Morris, Baruch Institute – University of South Carolina, co-I; P. Gayes, Department of Marine Science, Coastal Carolina University, co-I; S. Templeton, Department of Applied Economics and Statistics, Clemson University, co-I; J. Whitehead, S.C. Sea Grant Consortium, co-I. NOAA Sectoral Applications Research Program (SARP) #NA09OAR4310158. Project duration: May 2009 – June 2010. Funds Awarded: \$39,333 (note: 4 other sub-proposals sent with additional budgets).

4.3.2 Community Climate Adaptation and Resilience Projects (Whitehead, Dow, Carbone)

Abstract: These projects facilitated climate resilience and adaptation planning and work with coastal communities to identify infrastructure vulnerabilities and adaptation options for current climatic events as well as expected future risks associated with climate change (e.g., increased tidal flooding frequency under sea level rise).

Results: CISA was involved in several efforts to support climate adaptation planning in coastal areas. Specific examples are described below.

Plymouth, North Carolina. Whitehead, with partners at the Renaissance Computing Institute (RENCI) of East Carolina University, mapped historical patterns of erosion in Plymouth and sea level rise scenarios for the town. Fifteen mental modeling interviews in August-September 2010 with community leaders were used to establish a baseline of community knowledge, attitudes, and personal behavior towards the environment in general and flooding in particular. Analyses of these interviews were used to develop an outreach strategy that will assist the town in

exploring potential impacts of more frequent flooding exacerbated by sea level rise and identifying adaptation options.

Charleston, South Carolina. In partnership with the City of Charleston, SC, the NOAA Coastal Services Center (CSC), and the College of Charleston, the South Carolina Sea Grant team investigated potential sea level rise impacts and adaptation options for flooding on the Charleston peninsula. The team conducted a focus group with nine members of the City of Charleston planning and engineering staff and consultants on tidal flooding perceptions in downtown Charleston. The focus group members also gave feedback on “Visualizing Shallow Coastal Flooding and Sea Level Rise in Charleston, South Carolina,” a CSC product⁷ on increases in tidal flooding frequency with 0.5 m of sea level rise. Based on feedback from this group, CSC made extensive revisions and issued a new two-page fact sheet on historical tidal flooding trends in Charleston, which focus group members found more defensible and decision-relevant than maps of future projections that did not realistically account for stormwater infrastructure impacts on flooding patterns. The team also worked with the City of Charleston to develop an outreach strategy that will help the City initiate discussions on sea level rise adaptation in a challenging sociopolitical and economic context.

McClellanville, South Carolina. In fall 2010 Whitehead worked with the Kitchen Table Climate Study Group (KTCSG) to develop a strategy to catalyze adaptation planning activities. In January 2011 Whitehead led the group’s first advisory committee meeting to assess community risks and resilience in McClellanville. This advisory committee included CISA scientists (Carbone, Dow, and Whitehead) and McClellanville elected officials, managers, and residents. One outcome of this meeting was that the advisory committee members wanted to participate in a facilitated VCAPS exercise (see Section 4.3.3). This interest provided an opportunity to integrate several CISA and NOAA Sectoral Applications Research Program (SARP) projects.

Leveraged Funding Sources:

- “Preparing for Climate Change: Helping Small Coastal Communities Develop Adaptive Strategies.” J. Thigpen, NC Sea Grant, PI; G. Putnam, NC Sea Grant, J. Whitehead, SC Sea Grant Consortium, co-PIs. NOAA National Sea Grant Coastal Communities Climate Adaptation Initiative (CCCAI) program. Project duration: May 2010-October 2010. Funds awarded: \$30,000. (Plymouth, NC)
- “Preparing for Climate Change: Helping Small Coastal Communities Develop Adaptive Strategies.” J. Thigpen, NC Sea Grant, PI; G. Putnam, NC Sea Grant, co-I; J. Whitehead, SC Sea Grant Consortium & NC Sea Grant, co-I. Subcontract of SARP project “Mobilizing the NOAA Sea Grant Network for Coastal Community Climate Resilience” (J. Cone, OR Sea Grant, PI). Project duration: May 2010-June 2011. Funds awarded: \$14,000. (Plymouth, NC)
- “Assessing Flooding Adaptation Needs in the City of Charleston, SC.” R. Bacon, SC Sea Grant Extension, PI; A. Turner, J. Whitehead, SC Sea Grant Consortium, co-PIs. NOAA National Sea Grant Coastal Communities Climate Adaptation Initiative (CCCAI) program. Project duration: May 2010-October 2010. Funds awarded: \$30,000. (Charleston, SC)
- “Using Citizen Social Science to Investigate Climate Change Vulnerability and Resilience in McClellanville, SC.” J. Whitehead, SC Sea Grant Consortium & NC Sea Grant, PI; R. Bacon, SC Sea Grant Extension, co-I, S; D. Stoney, Kitchen Table Climate Study Group,

⁷ <http://www.csc.noaa.gov/digitalcoast/action/chsflood.html>

McClellanville, co-I. Subcontract of SARP project “Mobilizing the NOAA Sea Grant Network for Coastal Community Climate Resilience” (J. Cone, OR Sea Grant, PI). Project duration: September 2010-June 2012. Funds awarded: \$14,000. (McClellanville, SC)

4.3.3 Informing Coastal Management Adaptation Planning and Decision Making Using an Interactive Risk-based Vulnerability Assessment Tool (Whitehead, Dow)

Abstract: Successful adaptation and mitigation of climate change impacts in coastal regions requires the generation of realistic risk and adaptation scenarios and models in processes that pay close attention to producing knowledge that informs decision making and produces community acceptance. Local decision makers can benefit from a conceptual characterization of change and associated hazards that enables them to examine threats, consequences, and management interventions as a causal sequence resulting from a stream of choices and activities. The purpose of this research was to create a tool to help decision makers in small municipalities explore the potential outcomes and consequences of climate change in their towns, along with pathways through which they and individuals may respond. The resulting tool, Vulnerability and Consequence Adaptation Planning Scenarios (VCAPS), integrates locally specific knowledge about social stressors with generalized scientific information about potential impacts and promotes deliberative-analytical dialogue among researchers and community managers and representatives.

Results: The team developed the tool in partnership with the Town of Sullivan’s Island, SC. After initial interviews, the team facilitated four structured diagramming workshops with town staff and elected officials in May 2010. The group members created user-generated diagrams to identify current management challenges that may be intensified by climate change and identified strategies to improve long-term planning efforts. An Adobe Flash-based computer diagramming tool was created to help organize and record what was learned. Feedback from the group indicated that the facilitated process catalyzed discussion on climate change that would not otherwise have occurred. The process benefited Sullivan’s Island stakeholders by helping them learn about diverse perspectives and understand complex management issues under climate change in ways they said would not have been possible had the diagrams been completed by an outside party. This approach also deepened the research team’s understanding about local adaptation processes. In response, the research team refined the tool and packaged it as part of an overall facilitated modeling methodology called the Vulnerability and Consequence Adaptation Planning Scenario (VCAPS) process.

In March-April 2011, the team repeated the VCAPS process with a group of decision-makers from McClellanville, SC. The process focused on stormwater, and as a result, elected officials participating in the exercise asked for assistance from CISA and SC Sea Grant to create a town stormwater plan that accommodates increasing rainfall variability. They also requested a repeat VCAPS exercise at a later date to focus a second diagramming discussion on preserving the character of their historic fishing village under climate change. The project team authored a 4-page summary document of the case and conducted follow-up participant interviews with six members of McClellanville’s management boards who participated in the VCAPS exercises.

In October 2011, the team met with seven community leaders and managers in Plymouth, NC. The group met for a discussion and scenario building process focused on a complex discussion of stormwater management and the town's wastewater infrastructure.

Project findings highlighted how the process benefits stakeholders by catalyzing discussion on climate change that would not have otherwise have occurred and helping participants learn about diverse perspectives and understand complex management issues under climate change. Participants found this mediated modeling process helpful in identifying several "no regret" strategies, trade-offs, cross-scalar barriers, and potential innovative strategies.

Another set of activities entailed disseminating information about the approach and providing VCAPS training to other outreach specialists. Because VCAPS communities all expressed the value of outside facilitation, the research team turned its attention to how to train appropriate outside facilitators who could use the VCAPS process in their communities. The team completed a user guide designed to help outreach staff facilitate VCAPS exercises and conducted VCAPS training workshops at the following events: Gulf of Mexico Climate Outreach Community of Practice workshop (Biloxi, Mississippi, June 1-2, 2011), Coastal Zone 2011 meeting (Chicago, Illinois, July 17, 2011), Social Coast Forum (Charleston, South Carolina, February 15-16, 2012), and a Mississippi-Alabama Sea Grant Consortium webinar (March 1, 2012). CISA's partner, the Social and Environmental Research Institute (SERI), has maintained VCAPS information on their [website](#). Resources include a facilitation guide for implementing VCAPS, an Introduction to the VCAPS Process report, and conference presentations.

Leveraged Funding Sources

- "Informing Coastal Management Adaptation Planning Using an Interactive Risk-Based Vulnerability Assessment Tool." S. Tuler, Social and Environmental Research Institute, Greenfield, MA, PI; T. Webler, SERI, co-I; K. Dow, Dept. of Geography, Univ. of South Carolina, co-I; J. Whitehead, SC Sea Grant Consortium, co-I. NOAA SARP #NA09OAR4310151. Project duration: August 2009 – March 2011 (1-year no-cost extension until March 2012). Funds awarded: \$213,886.
- "Using Citizen Social Science to Investigate Climate Change Vulnerability and Resilience in McClellanville, SC." J. Whitehead, SC Sea Grant Consortium & NC Sea Grant, PI; R. Bacon, SC Sea Grant Extension, co-I, S; D. Stoney, Kitchen Table Climate Study Group, McClellanville, co-I. Subcontract of SARP project "Mobilizing the NOAA Sea Grant Network for Coastal Community Climate Resilience" (J. Cone, OR Sea Grant, PI). Project duration: September 2010-June 2012. Funds awarded: \$14,000. (McClellanville, SC)
- "Preparing for Climate Change: Helping Small Coastal Communities Develop Adaptive Strategies." J. Thigpen, NC Sea Grant, PI; G. Putnam, NC Sea Grant, J. Whitehead, SC Sea Grant Consortium, co-PIs. NOAA National Sea Grant Coastal Communities Climate Adaptation Initiative (CCCAI) program. Project duration: May 2010-October 2011. Funds awarded: \$30,000. (Plymouth, NC)
- "Preparing for Climate Change: Helping Small Coastal Communities Develop Adaptive Strategies." J. Thigpen, NC Sea Grant, PI; G. Putnam, NC Sea Grant, co-I; J. Whitehead, SC Sea Grant Consortium & NC Sea Grant, co-I. Subcontract of SARP project "Mobilizing the NOAA Sea Grant Network for Coastal Community Climate Resilience" (J. Cone, OR Sea Grant, PI). Project duration: May 2010-June 2011. Funds awarded: \$14,000. (Plymouth, NC)

- “Improving understandings of consequences, vulnerabilities, and adaptation strategies to climate change related hazards.” Tuler, Webler, and Dow. MIT Sea Grant. NA10-OAR-4170086. Project duration: Feb 2011-Jan 2013. Funds Awarded: \$237,543

4.3.4 Regional and National Collaborations: Formation of a Sea Grant Climate Network (Whitehead)

Abstract: The objective of these collaborations was to increase the capacity of the Sea Grant network regionally and nationally to research and deliver outreach programs on the impacts of climate variability and change for coastal stakeholders.

Results: Regional efforts entailed working with the NOAA Southeast Caribbean Regional Team (SECART) to establish a community of practice that facilitates regional collaboration on climate outreach. Whitehead helped to plan the 2010 Southeast and Caribbean Climate Outreach Workshop: “Building a Community of Practice of Climate Extension and Outreach Professionals.” This workshop contributed to knowledge coordination among outreach professionals working on climate issues, climate adaptation training for attendees, and the development of a web-based resource portal and forum to maintain collaborations after the workshop.⁸ Whitehead also worked with the SECART Climate Outreach Community of Practice to secure funding for and plan a 2012 workshop.

National-level activities included involvement with the Sea Grant Climate Network (SGCN), a grassroots organization for Sea Grant employees who work with or have an interest in climate variability and climate change. As co-chair for the Steering Committee of the Sea Grant Climate Network, Whitehead assisted with coordinating grassroots support for climate outreach throughout the Sea Grant network. The network has over 300 members and has been critical in fostering new partnerships across Sea Grant programs. In October 2010 Whitehead received a Chairman’s Award (with C. Conger, Hawai’i Sea Grant) from the Assembly of Sea Grant Extension Program Leaders for her leadership efforts.

Leveraged Funding Sources:

- “Enhancing Capacity for Climate Engagement in the Southeast and Caribbean Region of the United States.” C. Hopkinson, Georgia Sea Grant, PI; G. Olmi, NOAA Southeast and Caribbean Regional Team, co-I; S. Fauver, NOAA Coastal Services Center, co-I; J. Whitehead, SC Sea Grant Consortium & NC Sea Grant, co-I. Project duration: November 2009 – October 2010. Funds awarded: \$25,000.
- “The Sea Grant Climate Network: Informing Coastal Communities on Critical Issues.” R. Bacon, SC Sea Grant Extension, PI; J. Whitehead, SC Sea Grant Consortium, co-I; C. Conger, Hawai’i Sea Grant, co-I. NOAA #NA06OAR4170015, Project duration: August 2009 – December 2010. Funds awarded: \$34,960.

4.4 National Climate Assessment

CISA conducted several research projects to support the National Climate Assessment during 2010-2012. The intent of these studies was to identify key climate sensitive decisions, improve our understanding of decision-support needs, and assess the multiple dimensions of adaptive

⁸ Available at <http://collaborate.csc.noaa.gov/climateadaptation/pages/scceocp.aspx>

capacity in the region. CISA staff contributed three technical reports to the NCA and partnered with the Southeast Climate Consortium (SECC) and Southern Climate Impacts Planning Program (SCIPP) to coordinate writing of the technical input for the Southeast regional chapter. We received a supplement to our core funding from the National Climate Assessment for this work. Individual projects are discussed below.

4.4.1 Collaboration with Key Climate Service Providers (Dow, Boyles, Mizzell)

Partners: Southeast Regional Climate Center (SERCC), the Southeast Climate Consortium (SECC), and the state climatologists of the SERCC (Alabama, Georgia, Florida, North Carolina, Puerto Rico, South Carolina, and Virginia)

Abstract: This project entailed systematically documenting and evaluating climate information requests made of the SERCC and affiliated State Climate Offices.

Results: The group of partners collaboratively developed an on-line climate information request reporting system for the region's state climate offices (SCOs). CISA coordinated the data coding and production of summaries. This systematic effort was designed to help us identify shared concerns and needs and inform the coordination and development of climate service efforts. Data gathered through this project demonstrated the diversity of clients served by State Climate Offices and the Southeast Regional Climate Center. Although the media, colleges and universities, and personal interests were the most frequent users of climate information, there was a wide range of other users across the Southeast. These climate-sensitive sectors include agriculture, construction, economic development, energy, engineering, insurance, and tourism. Information on precipitation and extreme events were the two most frequently requested sources of climate information across all users and sectors. However, there was great variability within each information request category. For example, precipitation requests varied according to measurement interval (annual, seasonal, daily, hourly), geographic area of interest, and data type (observational, annual, or 30-year normal). The broad range of engaged clients and the detail of their information needs is suggestive of larger, more diverse group of advanced climate information users that are typically acknowledged by the climate adaptation community.

Leveraged Funding Source: The SERCC provided funding to support the data collection efforts in Virginia and Puerto Rico.

4.4.2 Engaging Climate-Sensitive Sectors in the Carolinas (Lackstrom, Dow)

Partners: Great Lakes Integrated Sciences and Assessments (GLISA), Western Water Assessment (WWA)

Abstract: This project involved assessing the capacity of five climate-sensitive sectors (forestry, government, tourism, water, and wildlife) in the Carolinas to adapt to climate change. This project also included a systematic review of publications identifying climate information needs for the region and which was done in collaboration with research teams from the Great Lakes Integrated Sciences and Assessments (GLISA) and Western Water Assessment (WWA).

Results: Document analysis and coupled online questionnaires-interviews with 117 decision makers engaged in climate decisions and activities informed this project. The study focused on three sets of issues. First, the study identified and examined primary climate and weather concerns, the major providers of climate information, what types of climate and weather information are used in decision making, and the factors that influence why specific sources are used. Second, the project identified and examined what types of climate change activities are planned or underway, how these activities are framed, and the factors that have facilitated or constrained these activities. Third, the study assessed the existing adaptive capacity to respond and adapt to climate change, the current needs and recommendations to increase adaptive capacity, and how those needs may be met. We collaborated with two other RISAs (Great Lakes Integrated Sciences and Assessments, Western Water Assessment) to design and implement the document analysis framework.

This project yielded significant information regarding existing adaptive capacity to respond and adapt to climate change. At this stage, adaptation is limited in the Carolinas, although some current activities indicate emerging action related to climate change – for example, efforts to improve climate-related data collection and monitoring, emissions reduction programs, education and outreach to increase awareness of climate information and issues, risk and vulnerability assessments for emergency management planning, and habitat protection and conservation projects. Factors that have facilitated climate change (and related) activities in the Carolinas include opportunities to engage in networks and collaborative projects, availability of resources (including availability of staff and expertise), availability of relevant data and information, and the existence of laws, policies, or regulations that support or motivate action on climate issues.

4.4.3 Contributions to the Southeast Region Technical Report (Dow)

Partners: Centers for Disease Control and Prevention; Eastern Forest Environmental Threat Assessment Center, US Forest Service; Georgia Sea Grant; Louisiana State University, School of Renewable Natural Resources; Marshall Space Flight Center, NASA; Mississippi and Alabama Sea Grant; NC State University, Forestry and Environmental Resources; Southeast Climate Consortium; Southeast Regional Climate Center; Southern Climate Impacts Planning Program; University of Georgia, Department of Marine Sciences; US Department of Transportation – Region IV; US EPA – Region IV.

Abstract: CISA, with the Southeast Climate Consortium (SECC), the Southern Climate Impacts Planning Program (SCIPP), and other regional partners, helped to create a technical report for use in developing the Southeast regional chapter of the 2013 National Climate Assessment.

Results: A workshop to identify chapter authors and outline report chapters was held in September 2011, in Atlanta, Georgia. In November 2011, CISA hosted a webinar introducing the National Climate Assessment process and soliciting contributions to the SE Technical Report. Invitations were sent to over 300 senior staff of state agencies in Alabama, Georgia, Florida, Kentucky, Louisiana, Mississippi, North Carolina, Puerto Rico, South Carolina, Tennessee, and the US Virgin Islands. Invitees were encouraged to forward the invitations to appropriate personnel within their organization. The final report was submitted to the National Climate Assessment in 2012.

Climate Adaptation in the Southeast

Kirstin Dow authored the adaptation chapter of the Southeast Region Technical Report with Lynne Carter of SCIPP. This chapter identified and examined the types of climate adaptation activities taking place in the Southeast. The majority of current climate adaptation efforts in the Southeast are aimed at initial steps of identifying the relevant climate risks and conducting risk and vulnerability assessments. Coastal areas, where risks of severe storms and sea level rise are highly salient, are frequently the focus of attention. Many efforts are working also to mainstream climate adaptation into existing institutions and processes. Partly as a consequence of that mainstreaming approach, adaptation efforts are being conducted under a variety of different names and terminologies, including resilience and sustainability. The adaptation process is much more complex and less linear than conveyed by basic models. Significant effort is going into building necessary partnerships for coordinated response of jurisdictional authorities and financial, technical, and other resources. In the future, as more groups advance from conducting risk and vulnerability assessments to strategic adaptation planning and implementation, we anticipate a shift in activities and information needs to place great emphasis on information on the costs, benefits and co-benefits of adaptations. As efforts advance, support for evaluation of adaptation efforts will also become a greater information need in decision making.

5. PUBLICATIONS AND REPORTS

5.1 Journal Articles

- Kettle, N. P. 2012. Exposing Compounding Uncertainties in Sea Level Rise Assessments. *Journal of Coastal Research* 28 (1):161-173.
- Rhee, J., and G. J. Carbone. 2011. Estimating Drought Conditions for Regions with Limited Precipitation Data. *Journal of Applied Meteorology and Climatology* 50 (3):548-559.
- Rhee, J., J. Im, and G. J. Carbone. 2010. Monitoring agricultural drought for arid and humid regions using multi-sensor remote sensing data. *Remote Sensing of Environment* 114 (12):2875-2887.
- Dow, K. 2009. News coverage of drought impacts and vulnerability in the US Carolinas, 1998-2007. *Natural Hazards* 54 (2):497-518.
- Dow, K., R. Murphy, and G. J. Carbone. 2009. Consideration of User Needs and Spatial Accuracy in Drought Mapping. *Journal of the American Water Resources Association* 45 (1):187-197.
- Hwang, Y. S., and G. J. Carbone. 2009. Ensemble Forecasts of Drought Indices Using a Conditional Residual Resampling Technique. *Journal of Applied Meteorology and Climatology* 48 (7):1289-1301.
- Carbone, G. J., J. Rhee, H. P. Mizzell, and R. Boyles. 2008. A regional-scale drought monitoring tool for the Carolinas. *Bulletin of the American Meteorological Society* 89 (1):20-28.
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- Dow, K., and G. J. Carbone. 2007. Climate Science and Decision Making. *Geography Compass* 1 (3):302-324.

- Dow, K., R. E. O'Connor, B. Yarnal, G. J. Carbone, and C. L. Jocoy. 2007. Why worry? Community water system managers' perceptions of climate vulnerability. *Global Environmental Change-Human and Policy Dimensions* 17 (2):228-237.
- Rhee, J., and G. J. Carbone. 2007. A Comparison of Weekly Monitoring Methods of the Palmer Drought Index. *Journal of Climate* 20:6033-6044.

5.2 Reports

- Dow, K. 2012. *Climate Information Needs in the Southeast: Analysis of Requests*. Research Report: CISA-2012-02. Columbia, SC: Carolinas Integrated Sciences & Assessments (CISA). 14 pp.
- Dow, K., and L. Carter, eds. 2012. *Climate Adaptation in the Southeastern United States*. With contributions from A. Brosius, E. Diaz, R. Durbrow, R. Evans, S. Fauver, T. Hayden, B. Howard, K. Jacobs, G. Landers, S. McNulty, J. Nicholson, D. Quattrochi, L. Rimer, S. Shuford, S. Stiles, and A. Terando. In K. T. Ingram, K. Dow, L. Carter, eds., "Southeast Region Technical Report," submitted to the US National Climate Assessment. 27 pp.
- Gilbert, S., K. Lackstrom, and D. L. Tufford. 2012. *The Impact of Drought on Coastal Ecosystems in the Carolinas: State of Knowledge Report*. Research Report: CISA-2012-01. Columbia, SC: Carolinas Integrated Sciences & Assessments (CISA). 76 pp.
- Ingram, K., K. Dow, and L. Carter, eds. 2012. *Southeast Region Technical Report*. Submitted to the National Climate Assessment. 332 pp.
- Lackstrom, K., K. Dow, B. Haywood, A. Brennan, N. P. Kettle, and A. Brosius. 2012. *Engaging Climate-Sensitive Sectors in the Carolinas*. Research Report: CISA-2012-03. Columbia, SC: Carolinas Integrated Sciences & Assessments (CISA). 201 pp.
- Social and Environmental Research Institute (SERI), Carolinas Integrated Sciences & Assessments (CISA), and SC Sea Grant Consortium/NC Sea Grant. 2012. *Informing coastal management adaptation planning and decision making for climate change using an interactive risk-based vulnerability assessment tool*. Final Project Report, NOAA Award NA09OAR4310151. 14 pp.
- Lackstrom, K., K. Dow, S. Ferguson, and N. P. Kettle. 2011. *Understanding Needs for a Drought Early Warning System: Urban Water Systems in North Carolina*. Research Report: CISA-2011-01. Columbia, SC: Carolinas Integrated Sciences & Assessments (CISA). 31 pp.
- Lackstrom, K., K. Dow, S. Ferguson, and N. P. Kettle. 2011. *Understanding Needs for a Drought Early Warning System: Drought Impacts and Stresses on Coastal Ecosystems*. Research Report: CISA-2011-02. Columbia, SC: Carolinas Integrated Sciences & Assessments (CISA). 24 pp.
- Mizzell, H. P. 2011. *Addressing Changing Needs for Climate Information*. Columbia, SC: South Carolina Department of Natural Resources. 20 pp.
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- Tuler, S., T. Webler, K. Dow, and J. C. Whitehead. 2011. *Diagramming Climate Change-Related Vulnerability-Consequence Adaptation Planning Scenarios (VCAPS): A facilitation guide and tutorial*. Greenfield, MA: Social and Environmental Research Institute. 34 pp.

- Whitehead, J. C., R. De Voe, D. L. Tufford, K. Dow, and G. J. Carbone. 2011. *Assessing the Impact of Salt-Water Intrusion in the Carolinas under Future Climatic and Sea-Level Conditions*. Final Project Report, NOAA Grant No. NA08OAR4310715. Charleston, SC: South Carolina Sea Grant Consortium. 23 pp.
- Whitehead, J. C. 2009. *Coastal Climate Impacts: What You Can Do*. Fact Sheet. SCSGS-G-09-02/UNC-SG-09-05. 4 pp.

5.3 Conference Proceedings Papers

- Lackstrom, K. 2011. "Institutional Opportunities and Barriers to Climate Adaptation." Paper read at 2011 American Water Resources Association Spring Specialty Conference, Managing Climate Change Impacts on Water Resources: Adaptation Issues, Options, and Strategies, April 18-20, 2011, at Baltimore, MD.
- Conrads, P., E. Roehl, C. Sexton, D. L. Tufford, G. J. Carbone, K. Dow, J. Cook, and R. Daamen. 2010. "Estimating Salinity Intrusion Effects Due to Climate Change Along the Grand Strand of the South Carolina Coast." Paper read at 4th Federal Interagency Hydrologic Modeling Conference, June 27-July 1, 2010, at Las Vegas, NV.
- Conrads, P. A., E. A. Roehl, R. C. Daamen, J. B. Cook, and C. T. Sexton. 2010. "Development of Decision Support Systems for Estimating Salinity Intrusion Effects due to Climate Change on the South Carolina and Georgia Coast." Paper read at South Carolina Water Resources Conference, October 13-14, 2010, at Columbia, SC.
- Conrads, P. A., E. A. Roehl, R. C. Daamen, J. B. Cook, C. T. Sexton, D. L. Tufford, G. J. Carbone, and K. Dow. 2010. "Estimating Salinity Intrusion Effects due to Climate Change on the Lower Savannah River Estuary." Paper read at 2010 South Carolina Environmental Conference, March 13-17, 2010, at North Myrtle Beach, SC.
- Kettle, N. P. 2010. "Improving reporting of uncertainties in sea level rise assessments." Paper read at 22nd International Conference; Shifting Shorelines: Adapting to the Future, June 13-16, 2010, at Wilmington, NC.
- Lackstrom, K., and K. Dow. 2010. "Coastal Ecological Impacts of Drought: Needs for a Drought Early Warning System." Paper read at 2010 South Carolina Water Resources Conference, October 13-14, 2010, at Columbia, SC.
- Mizzell, H. P., G. J. Carbone, K. Dow, and J. Rhee. 2010. "Addressing monitoring needs for drought management." Paper read at 2010 South Carolina Water Resources Conference, October 13-14, 2010, at Columbia, SC.
- Dow, K., G. J. Carbone, G. Garfin, and M. Crimmins. 2008. "Developing a Drought Impact Reporting System for the Carolinas." Paper read at 2008 South Carolina Water Resources Conference, October 14-15, 2008, at N. Charleston, SC.
- Lackstrom, K. 2008. "Improving Drought Management Policy and Practice: Lessons from Drought and FERC Relicensing." Paper read at 2008 South Carolina Water Resources Conference, October 14-15, 2008, at N. Charleston, SC.

5.4 Theses and Dissertations

- Kabela, E. 2012. "NARCCAP Model Assessment and Future Climate Change Projections for the Southeastern United States." PhD dissertation, University of South Carolina, Columbia, SC.

- Kettle, N. 2012. "Coastal Climate Change Adaptation: The Influence of Perceived Risk, Uncertainty, Trust, and Scale." PhD dissertation, University of South Carolina, Columbia, SC.
- Felker, L. 2011. "Increased Perviousness Versus Urban Densification: Trade-offs Between Adaptation and Mitigation in a Changing Climate". Master's thesis, University of South Carolina, Columbia, SC. AAT1498147.
- Fowler, J. 2011. "Cartographic Communication of Point Level Uncertainty". Master's thesis, University of South Carolina, Columbia, SC. UMI Number: 1492260.
- Mizzell, H. 2008. "Improving Drought Detection in the Carolinas: Evaluation of Local, State, and Federal Drought Indicators. PhD dissertation, University of South Carolina, Columbia, SC. UMI Number: 3332270.
- Yorty, S. 2008. "Drought Impacts on Water-Based Recreational Businesses in North and South Carolina." Master's thesis, University of South Carolina, Columbia, SC. UMI Number: 1459913.
- Rhee, J. 2007. "A Regional Drought Monitoring System for the Carolinas." PhD dissertation, University of South Carolina, Columbia, SC. UMI Number: 3280352.

6. LINKS WITH OTHER NOAA PROGRAMS

Organization/Agency/Division	Project
National Estuarine Research Reserve System	<i>Coastal Climate</i> projects
National Climatic Data Center	Advisory Committee
National Integrated Drought Information System	<i>Coping with Drought</i> projects
Coastal Services Center	<i>Coastal Climate</i> projects; Advisory Committee
Regional Climate Services	<i>Coastal Climate</i> projects; Advisory Committee
North Carolina Sea Grant	Carolinas Coastal Climate Outreach Initiative (CCCOI); Advisory Committee
North Carolina State Climate Office	<i>Drought</i> and <i>National Climate Assessment</i> projects
Northeast Regional Climate Center	<i>Dynamic Drought Index Tool</i> project
NWS	<i>Coastal Climate</i> projects
South Carolina Sea Grant Consortium	Carolinas Coastal Climate Outreach Initiative (CCCOI); ; Advisory Committee
South Carolina State Climate Office	<i>Drought</i> and <i>National Climate Assessment</i> projects
Southeast Regional Climate Center	<i>Drought</i> and <i>National Climate Assessment</i> projects
Southeast and Caribbean Regional Team	<i>Coastal Climate</i> projects